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Original Article

RECENT ADVANCEMENTS IN ROBOT ASSISTED LOWER LIMB REHABILITATION TECHNIQUES

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ABSTRACT

Lower limb joint injuries are very common and are caused due to several reasons. In many cases, either after surgical procedure or even without it, rehabilitation is a highly important and necessary process. Rehabilitation is defined as 'the act of restoring someone's health to normalcy after a period of discomfort through exercise and therapy to improve their quality of life'. Rehabilitation can be of two types broadly – active and passive. Active rehabilitation techniques involve the patients to directly perform special exercises such as stretching, bending and folding taught by physical therapists. Passive techniques include some form of assistance which may be provided either manually by the therapist or by special machines designed to assist rehabilitation. Manual physiotherapy is not usually recommended immediately after trauma or procedure and robotic rehabilitation machines are used in the initial stages because of their safety of operation and angle precision. The purpose of this paper is, to review the recent advancements and innovations in this area. The robot-assisted motor rehabilitation is proven to be better than manual rehabilitation in many ways but in cases, where there are budget constraints, they may not be considered. The clinically viable methods that have been presented in literature are discussed in this paper and also possible suggestions for future developments in the same area are proposed.

***KEYWORDS:** Lower Limb Rehabilitation, Robot, Passive Therapy & Automatic*

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1. INTRODUCTION

The aim of rehabilitation is to restore the patient's physical, sensory, and mental capabilities lost because of illness, injury, and disease, and to aid in recovery that cannot otherwise be achieved by medical procedures [1]. Following spinal cord injury (SCI), stroke, muscle disorder, and post operation such as total knee arthroplasty, patients need rehabilitation to regain their movement capability (mobilization) [2–8]. The number of individuals in need of rehabilitation is steadily increasing day by day. Parallel to this, equipment and techniques used for rehabilitation purposes are becoming more and more advanced and sophisticated. There are two basic elements in the total rehabilitation program: therapeutic modalities and therapeutic exercise. While the objective of therapeutic modalities is to treat and reduce the effects of pain, spasm and edema, the ultimate objective of therapeutic exercise is to help the injured patient return to their original state of pain-free and fully functional activity. In order to have the patients safely resume fully normal activity, each of these following parameters must be restored to at least pre-injury levels. In the correct sequence these parameters are [9]:

- flexibility and range of motion
- strength and muscle endurance
- proprioception, coordination and agility.

To restore the range of motion and flexibility, special passive exercises are prescribed to by therapists, for the strength and muscle endurance, the patient is required to perform resistive exercises, and for the proprioception, coordination and agility, the physiotherapist assists the patient to perform certain strength exercises [7, 10].

To replace the role of physiotherapists in the rehabilitation process, the use of robotic devices has seen an increasing trend for the past three decades. Some of the most important reasons for the application of robots in the field of rehabilitation are [11]: Robots can easily perform the cyclic movements in rehabilitation as per the requirements; robots have better control over introduced forces; they can reproduce required forces in repetitive exercises with accuracy; and robots offer a higher level of precision regarding required therapy conditions.

Continuous Passive Motion (CPM) devices are widely used in rehabilitation of upper and lower extremities to perform the repetitive exercises to complement the role of a physical therapist. These devices have been in widespread use, since the 1970s [12]. Conventional CPM devices can perform only a single action, i.e. replicating the movement performed by the physiotherapist repeatedly throughout the session. They do not respond to any kind of reflexes from the patient expressed due to pain or discomfort. If due to sudden movements or improper loading on joints, the muscle or tendon tissues are damaged, it can lead to severe issues [13]. Therefore, there is a need for intelligent devices that are capable of sensing the responses of the patient and taking immediate action to prevent complications [14].

In this paper, we have discussed some of the innovations in robotic devices for lower limb rehabilitation from recent literature to list out their advantages and disadvantages and also a new prospective methodology has been proposed.

2. THE DESIGN AND CONTROL OF A THERAPEUTIC ROBOT FOR LOWER LIMB REHABILITATION: PHYSIOTHERABOT

Erhan Akdogan et al. proposed three degrees of freedom therapeutic robot for the rehabilitation of lower limb for patients suffering from spinal cord injury, stroke and post-surgical pain. This device consists of a robot manipulator, capable of performing all active and passive exercises and learners know specific exercise motions in the presence of physiotherapist and perform it later in their absence. Moreover, if the patient reacts against the robot manipulator during the exercise, it can sense the position and take necessary change according to the feedback.

The 3 DOF system consists of three links and is capable of performing the following actions.

- Flexion-Extension for the knee
- Flexion-Extension for the hip
- Abduction-Adduction for the hip

The robot manipulator has been carefully designed keeping in mind that, it must be able to accommodate different types of patients and also perform the required movements safely and effectively. It must also be able to measure the voluntary and involuntary forces exerted by the patient during the operation.

The main hardware components used in this device include – actuators, servo-drivers and gearboxes. There are three actuators (servomotors) and appropriate gearboxes, which enable the manipulator to handle up to 100kg. As for the feedback system, it has two force/torque sensors and their controllers positioned and calf and thigh locations, whose positions can be adjusted according to the patient. These sensors measure the voluntary and involuntary forces exerted by the patient and the therapist on the patient. Also, the position of the robot manipulator is obtained via the encoder emulation from the servo-drivers.

The Human-Machine Interface (HMI) acts as the central unit between the PT and the robot manipulator. All types of movements produced by the manipulator are controlled by the HMI. Furthermore, in a particular mode of operation, the device of capable of learning specific new movements in the presence of a physical therapist and perform it later. Also, the design of the HMI allows monitoring of the manipulator position, reaction force of the patient, and the force applied by the robot manipulator to the patient, and records the results of the exercises so that the treatment period can be followed.

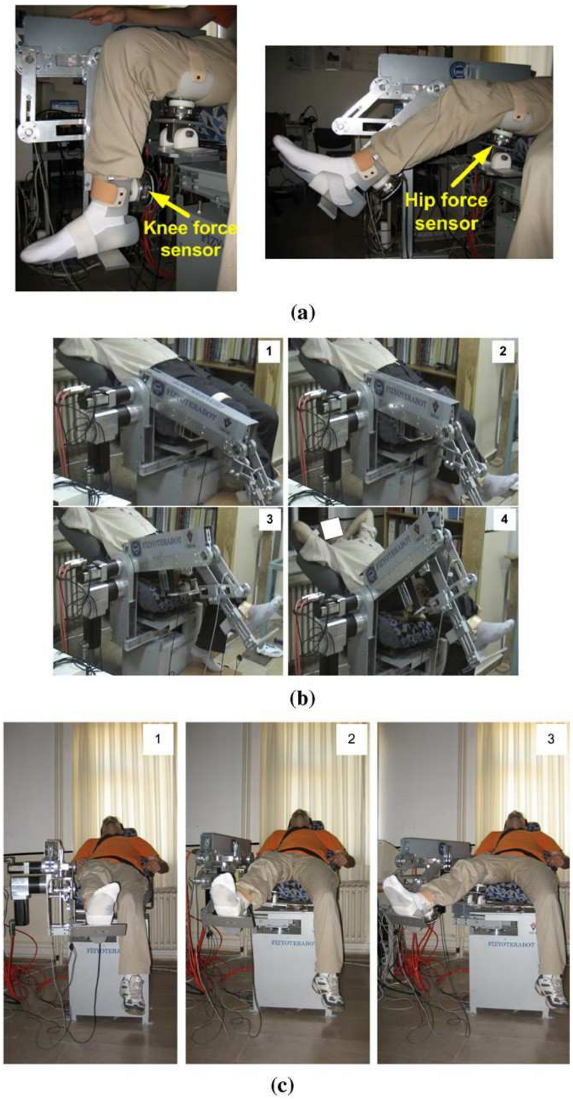

Figure 1: Exercise Movement Capacity of Robot Manipulator. (a) Knee Flexion Extension, (b) Hip Flexion-Extension, (c) Hip Abduction-Adduction

The important features of this device can be summarized as follows.

- It has a 3 DOF robot manipulator and can perform flexion-extension of the knee and hip, as well as abduction-adduction of the hip.
- It can perform active, passive, active-assistive exercises and also repeat specific exercises learnt from therapist in teaching mode.
- It can be used on both the legs and can accommodate persons up to 100kg.
- Force/Torque sensors are used to detect responses from the patient during therapy.
- A Human-Machine Interface is designed to control the entire process and to act as a central unit between the robot manipulator and physiotherapist.

3. DEVELOPMENT AND CONTROL OF A NEW SITTING TYPE LOWER LIMB REHABILITATION ROBOT

J. K. Mohanta and company proposed a sitting type lower limb rehabilitation device. The proposed device is a planar hybrid manipulator. The system can easily be converted to standing type body weight support (BWS) mechanism since it has modularity [15]. A PID controller is used for demonstrating the clinical gait pattern in order to validate the effectiveness of the proposed device.

There are two types of gait training devices, treadmill-based gait training devices, footplate-based gait training devices [16]. The proposed device in this paper is a foot plate based sitting type rehabilitation system. The author has based his publication on the previously available commercial products such as Motion maker [17], and various other proposed ideas such as, Physiotherabot [18] Lambda [19], Supine [20], improved Lambda [21] and ANKUR-LLII [22]. The author uses parallel manipulator over series manipulator considering its advantages over the later. Parallel manipulators, are used especially for its ability to handle greater loads, lower multiplication error, low links inertia even in stiff structures, simple kinematics design. Despite a few disadvantages of parallel manipulators, the author decides to use the parallel manipulators so as to enable them to fix the actuator in a stationary base.

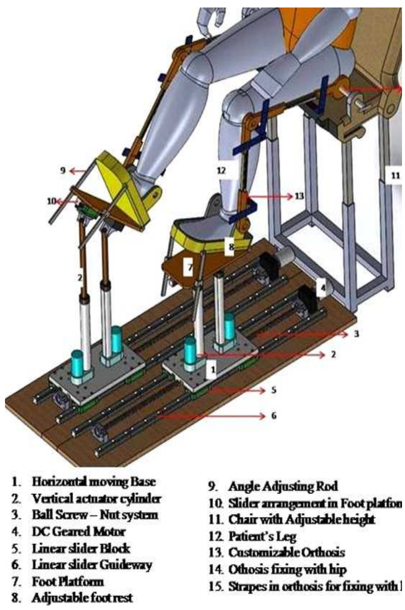

Figure 2: Conceptual Model of the Proposed Rehabilitation Robot

The proposed manipulator system is designed to have translational motion with three degrees of freedom. The mechanical advantages of the system are, self-locking nature, simple configuration and design. The manipulator has two aspects.

- active motion provider that provides motion to the leg(limbs) through powered actuators
- passive orthosis acts as support for weak leg by taking the axial forces and provide a stable motion for the leg.

The actuator inbuilt sensor is used to sense the load on the particular leg and thereby changing the resistance of the potentiometer, this helps drive the motor according to the load resistance thereby providing the required motion for rehabilitation.

4. CONCLUSIONS

The two devices discussed in this paper have been determined to be the most relevant and important in the lower limb rehabilitation devices found in recent literature. Their features and advantages have elaborately been discussed.

The therapeutic exercise robots for lower extremities are divided in two groups: leg, ankle, foot robots and walking (gait) robots [23].

LOKOMAT [24], Gait Trainer [25] and Autoambulator [26] are commercial gait rehabilitation devices and are available on the market. On the other hand, some prototypes for gait rehabilitation have been developed by researchers, such as ALEX [27], Haptic Walker [29] PAM and POGO devices of University of California, Irvine [30] and LOPES exoskeleton of Universiteit Twente [31]. Lower limb exoskeletal robots were developed to assist people who have some handicap in their lower extremities [32–34]. The robotic systems for therapeutic exercises for lower limbs were developed to perform some repetitive, resistive, and assistive exercises which are performed by the PT or equipment. Okada et al. employed an impedance control methodology in a 2-DOF robotic system, where the position and force data are received and recorded for the robotic system to imitate the corresponding motion [2]. Homma et al. developed a 2-DOF system around the patient’s bed [35]. They only tested it for passive exercises. Bradley et al. developed a 2-DOF autonomous system called NeXOS[3] that is able to perform active assistive, passive and resistive exercises using pre-training visual position information. It can be used for knee and hip extension–flexion movements.

But one of their major drawbacks is the cost and complexity involved. It might be difficult for the physical therapists to understand and implement them in real practice. Therefore, there is a need for a device that is simpler in construction and application and is also cost efficient. A generalized methodology for such a device is proposed as follows.

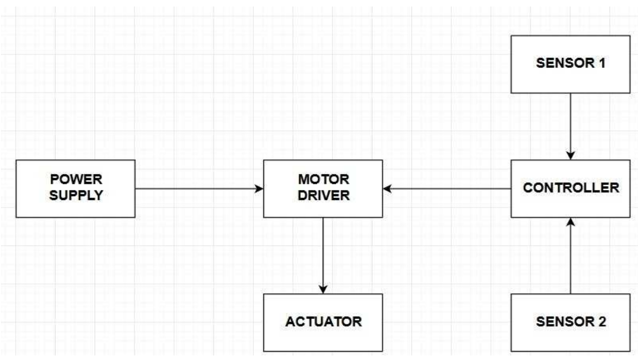

Figure 3: Proposed Block Diagram

The existing devices require all the working parameters such as flexion angle, extension angle, duration of therapy and rest time to be set prior to the start of the session by a physical therapist and he/she is also required to look over the process to change the setting in the middle, in case the patient feels any pain or discomfort. The proposed device continuously monitors if the patient expresses any pain by measuring the pressure exerted at specific positions and decides the correct range of motion for that particular session. This is done by taking feedback from one or more force/pressure sensors placed in locations such as knee, thigh and foot. The feedback values are used to calculate the correct range of motion, duration and other parameters required for the process.

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